The Road to the Hydrogen Economy: Beyond the NRC Report

Testimony of
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to
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The Honorable Chairman and Members of the Committee:

It is a pleasure for me to be called before you to discuss the subject of the R and D program of DOE for development of hydrogen energy– a matter of considerable importance to the future of the US energy security, as well as to our ability to reduce the risk of continuously raising the level of carbon emissions to the atmosphere, thus triggering fundamental changes in the Climate.

Main Recommendations of the NRC Committee on Hydrogen

In early 2004, the National Research Council Committee on Alternatives and Strategies for Future Hydrogen Production and Use published a report " The Hydrogen Economy: Opportunities, Costs, Barriers, and R &D Needs". As a member of that Committee, I had a chance to get acquainted with the scope of DOE's program that translates the President's initiative on Hydrogen into funding of research, development and deployment activities.

The main conclusions of the NRC committee were as follows:

- Hydrogen can, with appropriate development of technology, fundamentally change the US energy outlook by reducing the need for imported energy sources while also reducing the emissions of carbon dioxide and other regulated emissions.
- There are formidable technical hurdles, and non-technical hurdles to overcome, including economic, social and political challenges.
- There are many options for the production, distribution, storage and use of hydrogen, but none of the options satisfies the full combination of desired attributes. The R and D program should establish criteria to judge the potential technical and economic performance in each area, and allocate resources to

demonstrate the more promising area, while allowing the basic and exploratory ideas.

- The US must maintain a robust, balanced energy RD&D program in areas other than hydrogen, to maximize the likelihood of meeting the national goals.

Since issuing the NRC report, several developments heightened the need to push forward with preparing technologies and standards that maximize the chances for use of energy sources other than oil for our transportation needs. For a starter, the price of oil has more than doubled, while it will continue to fluctuate, it is not likely that it will ever go back to the level of 25 $/barrel that the NRC used in its assessment. Similarly, the price of natural gas has climbed from $3.5 per MBTU to more than $6. The price hike is indicative of the world-wide balance of supply and demand for these resources, which is likely to get worse with the growth of the economies of the largest two countries in the World: China and India. Realizing that the effective price of oil at $60 per barrel is only equivalent to what it used to cost at the end of the 1980s, it is not likely that it will come down much. That is the bad part. On the other hand, the current price of gasoline make it easier to introduce alternative technologies in the transportation sector.

Another important development is the certification of the Kyoto agreement by the requisite number of countries to put it into effect, which now will bring more pressure on our industry to offer technologies that are compatible with the desire by most of the World to limit the carbon emissions to the atmosphere.

A third important development is the rise in the level of uncertainty about the security of supply of oil and gasoline, due to the rise in the level of violence and terror in the Middle East, the region responsible for exporting most of the oil in the world. Whatever desirable objectives may have been behind invading Iraq, the outcome has been to increase the turmoil in that country, and potentially in neighboring oil rich ones, thus increasing the chances for interruption of oil flow to the rest of the World.

So, today there is a higher priority for the development of alternative energies that rely on domestic sources and do not increase carbon emissions. That means clean coal (i.e coal with sequestration of CO_2), nuclear energy and renewable energy. While in the last two decades we have seen a huge rise in the use of natural gas for energy consumption, it is clear that if this continues, the imports of gas would rise in time to reach the level of discomfort that we have today with oil, where more than 55% of our consumption depends on non-American sources. Furthermore, much of the imports would be in the form of liquefied natural gas (LNG), which is more expensive than pipeline gas from Mexico and Canada.

The R and D Recommendations

The NRC Committee emphasized the need for development of a systems analysis capability to identify the best options for the short, medium an long term policies and technologies to expedite the time at which hydrogen could be widely used in society.

The key priorities for the R and D objectives, as recommended by the committee, were

1) Development of cost effective and environmentally desirable mobile fuel cells that use hydrogen to power light duty vehicles.
2) Development of durable and safe hydrogen storage systems.
3) Development of the infrastructure needed to provide hydrogen for light duty vehicles throughout the country.
4) Reduction of the cost of hydrogen from CO_2-free sources, such as renewable and nuclear electricity plants, and increase the effort for efficient and inexpensive electrolyzer development.
5) Solving the CO_2 capture and sequestration issues, economically and safely.

The Committee advised that the area of hydrogen infrastructure deserved increased funding and support, especially for the transition period during which overcoming the hydrogen and fuel cell vehicle "chicken and egg" problem will need to be overcome. In particular:

- To focus on materials issues in distribution and storage of hydrogen.
- To Create better linkages between programs in large-scale and small-scale hydrogen production
- To Clarify conditions under which large-scale and small-scale hydrogen production will become competitive, complementary, or independent
- To explore new concepts for hydrogen delivery

The committee recommended strengthening the development of standards for safe handling of hydrogen and to increase the public understanding of the safety issues. There is a need to ensure that in the production, storage and shipping of hydrogen sufficient testing has been done to resolve safety issues ahead of large scale commercial use of hydrogen in industry. Similarly for the transition period in which hydrogen may be produced at filling stations either by electricity or using natural gas reformation

DOE has made good progress in many ways in reshaping its program along the lines recommended by the committee, but not in all the needed areas. On the positive side:

1- Increased coordination among DOE various offices (EERE, FE, NE, BS, and SC).
2- Increasing the total budget for the core hydrogen and fuel cell program from $144M in FY04, to 169M in FY05, and a budget request for FY06 of $183M.
3- Refocusing some of the research, for example away from on-board reformation of gasoline, and into other more promising areas, such as on high pressure hydrogen storage tanks in the short term and advanced materials in the long term. (Some overlap with the Freedom Car project).
4- Increased funding in the area of infrastructure, and its technology verification
5- Increasing the hydrogen related research funded from the office of basic science in such areas as nanomaterials and membrane sciences.

However, progress in other areas has been slow. For example, the needed systems model to assess the evolution from near term technology to long term technologies is still being planned. Further more, the area of demonstrating low cost hydrogen production technologies has not been planned out, at a time when the price of gasoline has climbed to almost twice the levels at the NRC report was released.

Systems Analysis of US Energy Options

The development of a systems analysis model for the evolution of the entire energy program should have been far ahead by now. Instead, the program still relies on piecemeal analysis of each option, which often misses the links between various systems. The NRC called for the systems analysis effort "both to coordinate the multiple parallel efforts within the hydrogen program and to integrate the program within a balanced overall DOE national energy R and D effort. In particular to clarify the competition between electricity, liquid-fuel-based, and hydrogen based transportation."

The evolution of the technology advances in the alternative power trains for vehicles is such that it is very hard to pick an ultimate winner today. Progress is being made on batteries and on alternative liquid fuels, and both of these options has the potential to rely on domestic fuel sources, and to reduce the carbon emissions to the atmosphere. In addition, these two options can use the existing infrastructure. This a huge advantage vis a vis hydrogen, which requires a new infrastructure as well as a new technology for powering the car. The penetration rate of these two options could be such that they would satisfy the market well before the goals for the hydrogen fuel cell can be attained.

While it is possible to have hydrogen from carbon-free sources, it is also possible that it would be derived from a hydrocarbon source. Today, 95% of the hydrogen is made out of natural gas. If we take a somewhat optimistic scenario about growth of market share of hydrogen driven cars, our need for imported natural gas could be doubled by the year 2035, over what it would have been otherwise, and nearly four times what we import today. Today we import about 18% of our natural gas, a lot of which comes from Canada and Mexico. Future imports would rely more heavily on LNG, which would be much more expensive. Continuing to rely on natural gas for the production of hydrogen has its pitfalls in terms of energy security and environmental impact.

If the price of natural gas continues to rise, it will reach a point that the competing technologies of batteries and liquefied coal will be economically competitive with the hydrogen fuel cells. Such a comparison would be very useful to prioritize funding for the promising technology. The comparison should take into account the amount of funding that it would take to create the infrastructure for the distribution of each fuel.

Reexamination of Market Needs of Hydrogen

Almost half of the hydrogen produced in the US today is used at oil refineries for lightening the heavy oils to improve the products of vehicle and aircraft fuels. This use is likely to grow as we extract heavier oils in the US and in Central and South America. With time the need will grow as even heavier oils are extracted from shale and tar, in the US and Canada. Given the size of the unconventional oil resources in North America (about 15,000 ExaJoules, as compared to 2,500 ExaJoules of conventional oil reserves in the Middle East), it is very likely that they would become a major source for our oil. In fact, Canada already produces aver a million barrel a day from tar sands, getting the needed heat from burning natural gas. The heat and hydrogen needed to sweeten the shale and tar-sand oil, could be produced from other sources such as renewable and nuclear sources, to avoid the carbon emission to the atmosphere.

Hydrogen production may become more important for the generation of liquid synthetic fuels before it becomes important for fuel cell vehicles. In particular a source of synthetic liquid fuel might become very attractive, which is the off gas carbon dioxide from coal fired electric power plants. If this gas is captured, and combined with hydrogen extracted from water by electrolysis or chemical means, it could become a source of alternative liquid fuel, such as methanol, ethanol or even gasoline and diesel fuels. Liquid fuels are ready, or easily adapted, for distribution using much of the established infrastructure. This will help solve the problem of imported oil, but it would only partially address the problem of carbon emissions, by eliminating or reducing emissions from fossil powered electric plants but not from vehicles. The technology is well known and has been demonstrated in Germany and New Zealand. The question is how economic is it now or in the future? The answer should be sought by DOE planners, with the aid of a systems analysis model. However, in a market with escalating prices of gasoline, and mounting desire to reduce carbon emissions, the answer is likely to be well before 2050

Hydrogen Production: The Case for Nuclear Energy

The technology for production of hydrogen on a large scale from fossil fuels is well established. The technology for distributed generation by electrolysis or small reformers, is available but could be improved. The technology to produce hydrogen from a non-emitting source, such as renewable or nuclear energy, is available but expensive. The application of electrolysis to produce hydrogen from hydro, wind, solar or nuclear energy would eliminate the emissions of CO_2 from the process. However, selling the product of electricity in the market is more financially rewarding than selling hydrogen.

Improving the cost of hydrogen production from electrolysis could come by using high temperature steam electrolysis using Solid Oxide Electrolysis Cells (SOEC), a process which has recently been demonstrated on a lab scale at Idaho National Laboratory. The electrolyzer cell energy efficiency of such a process was close to 90%, at a temperature of 850 C; this is a bit higher than the conventional electrolysis cell efficiency of 80%. However if the electricity and heat were provided by an advanced high temperature nuclear reactor, the overall efficiency could be 40% for the high temperature electrolysis, vs 35% for the low temperature electrolysis. Renewables as well as nuclear electricity can be used for either low temperature or high temperature electrolysis. However, for large scale and continuous production, to avoid the need for large storage facilities, hydro and nuclear have an advantage over wind and solar. In addition, they would provide a lower cost options. Unfortunately, hydro power expansion potential is limited, but luckily, nuclear expansion is quite possible.

The production of hydrogen from nuclear is also possible using high temperature chemical reactions using heat alone (the so called thermochemical approach). At temperatures above 850 C, water splitting into hydrogen and oxygen become feasible with an energy efficiency over 40%. This possibility has been tested and shown to work in the US and Japan, on a small scale. In Japan, the process was coupled to a new type or nuclear reactor which allows reaching a very high temperature. This experiment was demonstrated on a small scale of 30 liters per hour last December. They are now moving ahead with a project for 30 cubic meters per hour, or 1000 times bigger. The project will be coupled to their 30 MW high temperature nuclear reactor that started operation in 2001. China also has a high temperature small reactor, and plans to couple it with hydrogen production are being made today.

In the US, we have no operating high temperature reactor. The DOE, as part of the international GEN IV program, selected this type of reactor as one of 6 concepts that would be useful as advanced reactors. It was designated as the first priority in the US GEN IV program, and plans to build a demonstration project in the future, named The Next Generation Nuclear Plant (NGNP), were initiated. However, it appears today that the program is retreating from the plan to build a demo plant, as the FY06 budget has no request for such an acquisition. It would be a mistake in my opinion to delay the testing of the technology needed to integrate a high temperature reactor with the hydrogen production technologies and be ready for commercial application by 2020.

The NGNP project relies in part on demonstrated technology, but needs certain developments before a plant is built:

1) Development of fuel manufacturing capability with a high quality control, starting with an oxide fuel but testing oxicarbide fuel on the way, and testing the irradiation effects on the fuel.
2) Development of a design for a heat exchanger capable of facilitating the interface between the nuclear and hydrogen islands
3) Development of helium turbo-machinery, as none has been built on a wide scale any where in the world. An alternative CO2 power cycle should be developed as well.

Thus, the above development could proceed in parallel with the design and licensing of a demo plant, and in the span of 5 to 7 years we could be ready to start construction of the plant. Assuming it could be built in three years and tested in various operational modes for five years, commercial viability and modifications could be ready in 15 years, i.e. By 2020. If the project is delayed, it would only delay the availability of this technology on a commercial scale.

The NRC committee assessed the potential future cost of production of hydrogen from various sources. The committee concluded that in 2003 the most economic means of hydrogen production was conventional Steam Methane Reformation or SMR (i.e. using natural gas), but that hydrogen production from electrolysis using modern Integrated Coal Gasification plants and high temperature nuclear reactors could very well compete with these means. Today, with the price of natural gas is much higher than in 2003, the economic comparison can only be better.

Furthermore, It is by no means certain that we will be able to sequester massive amounts of CO_2 from coal production of H -- and with any degree of certainty that they will stay sequestered. We also do not know what long term effects that would have on the sequestration reservoirs. Standards for sequestration have yet to be devised, and the debate about the ramifications has only begun. The issue mirrors the nuclear waste debate in the late 1960s, when everybody "knew" that the salt domes in Lyons, Kansas were the answer.

Even if some form of CO_2 sequestration were to work, an energy monoculture would not serve us well. We would be better served having both domestic sources nuclear and clean coal available to help fuel our transportation system in the future.